# DEFINING FACTORS SIGNIFICANT FOR OPTIMISATION AND MANAGEMENT OF TECHNOLOGICAL PROCESS FOR GREEN BANANA FRUIT RIPENING

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This paper has a purpose of defining factors affecting process optimization and improvement of green banana fruit ripening technology, not only on the territory of the Republic of Serbia where the research was performed, but wider, as well. On the sample of 144 fruit ripening treatments, according to the three-factor experiment with three main parameters (the land of origin, process temperature and concentration of ripening gas) the influence of factors significant for production process and end fruit quality was examined. Out of the group of 72 internal and external indicators, 13 variables with the highest influence on process efficiency and optimization were selected and formed. By implementing various tests ("Shapiro-Wilk", Kruskal-Wallis H non parametric test, ANOVA analysis) on the basis of key confirmatory factor analysis as well, 4 factor groups were attained. The first group F1 consists of internal ripening process factors and it illustrates 29.4% variance, and at this percentage, it is significant for process optimization. The second group F2 consists of by-products or post-factors incurred after processing, explaining 17.1% variance. The third group F3 are external ripening factors with variance explanation of 15.1%. At the end, the fourth group F4, where there are other factors significant for processing and optimization of ripening process, with 9.2% variance. The research has shown that in 71% of cases, with adequate management and regulation of certain factors an optimization and efficiency of banana ripening process can be influenced, whilst acquiring satisfactory fruit quality and attaining profit. The paper leaves possibilities for further theoretic research and it is of a great significance for companies inside which banana fruit processing are being held in controlled environments.

**Keywords:** banana, ripening technology, process optimization, efficiency, confirmatory factor analysis

## Introduction

Fruit storing technology in controlled environment, also including green fruit thermal processing is at the very top by importance in agricultural-food industry on a global level. According to [1], a banana in the world market by importance belongs to the 5 most important food items after crops, sugar, coffee and cocoa. World banana production on an annual level is 114 million of tons on the surface area of 5.6 million of hectares [2].

Banana is a climacteric fruit, picked when green, and for the fruits to have a consumable value, they are being subjected to artificial ripening in special ripening chambers, in which one can control temperature, ethylene concentrations, air humidity [3]. Ripening represents a combination of processes on physiological, biochemical and molecular level taking place inside and on the very fruit, as a result of which it comes to pigment alterations, in contents of acids and sugar, alterations of fruit structure and composition, flavor and taste, etc. [2]. Alteration of organoleptic properties, implying development and change of color on the fruit peel, represents an important index by which the degree of banana ripeness is being appraised. Change of color during fruit ripening incurs by modification of existing pigments as a consequence of chlorophyll degradation and synthesis of anthocyanins and carotenoides [4].

The most important factors influencing green fruit thermal processing are temperature, ethylene and time in mutual correlation. Ethylene as a herbal hormone, initiates a sequence of chemical reactions within the fruit, leading to fruit ripening including the change of color, smell, taste and composition of the fruit (contents of starch, water, sugar etc.) [5]. Temperature of the chamber in which the fruit is stored is significantly affecting ethylene production. Ethylene production is generally decreasing in low temperatures [6]. Fruits

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being exposed to lower temperatures and lower ethylene concentrations, require more time to ripe in regard to those fruits ripening on higher temperatures and with higher ethylene concentrations. On the other hand, higher temperature and higher ethylene concentrations have a huge influence on deterioration of quality and faster fruit decay. Exposure of banana fruit to adverse temperatures leads to many physiological disorders, such as tissue decay due to excessive cooling or heating [7].

Banana belongs to the group of perishable fruits, it loses its quality during storage and it comes to fruit spoilage. Fruit loses freshness, structure and constitution, characteristic color, due to physical, physiological and pathological factors [8]. Deterioration of quality inflicting company losses, incurs during the production process exactly due to poor storing conditions and infrastructure, poor product manipulation, inadequate process organization [9]. According to [10], fruit quality perseveres after the harvest is improved and maintained by modern technology, innovations and improvements. It is necessary to increase investments in storage, modernize transport, upgrade knowledge, and educate employees, etc. in order to improve processing technology, therefore decrease rapid fruit decay and enormous losses [11]. Banana loss assessment in developing countries is 20-40% while losses in the developed countries are in the range of 10-15% [12]. The above-mentioned shortcomings are present in this area, as well.

In this paper the possible solutions relating to defining factors that affect optimization of processes for green fruit thermal processing are represented. In order to achieve higher degree of efficiency, out of 72 factors, 13 of internal and externals factors were selected and analyzed with the most influence on banana ripening optimization process. The target of the research is to act upon factors affecting the process optimization by correcting the selected parameters, in order to achieve standardized fruit quality without losses and gain profit in the end. Beside theoretical contribution, the paper also has a practical meaning because it provides justified guidance for the companies in which green banana fruit ripening processes are being realized.

## Material and methods

The research was practiced in chambers of Logistic Distribution Center Niš. Ripening plant consists of storage for green bananas in capacity of 140.000,00 kg and six ripening chambers in capacity of 245.000,00 kg. Research time period was since 2018 up to 2022.

The subject of the paper represents research of factors affecting the optimization of technological process for green banana fruit ripening. The target of the paper derives from the subject of the research and relates to defining adequate ripening factors which can be used to affect process optimization. Therefore, by researching it can be shown that by regulating selected internal and external factors, including other processing factors, processing can directly or indirectly be affected on, in order to attain standardized quality, which will fulfill consumers expectations, as well as company needs regarding efficiency, reduction of loses and costs, gaining profit. The specific research targets are:

- determine the significance of temperature and concentration of ripening gas to banana ripening process;
- examine the importance of fruit temperature at reception and month in which the ripening was realized;
- examine the significance of ripening process time length;
- examination of incurred discrepancies from planned ripening time and their relevance for banana processing;
- examination of relevance for graded fruit peel color at the end of the process and ungraded peel color degree;
- determine the importance of ripening shrinkage, respectively commercial loss incurring after ripening process;
- determination of relevance for banana storing and time fruit spends in the ripening chamber in green and yellow phase.

For the realization of this research, a green banana fruit type Cavendish was used, imported from the Republic of Slovenia by supplier Rastoder Ltd. Ljubljana. Fruit origin countries are: Ecuador, Costa Rica, Columbia. The fruits used belong to the various brands and companies: Derby, Slobana, Chiquita, Sentiliver, Pamela, Amigo, Bonanza, Consul etc. For initiating the ripening process, a ripening gas was used by the supplier “MESSER” (Tehnogas, Belgrade). Gas represents mixture containing 95% Nitrogen (N) and 5 % ethylene ($C_2H_4$). Gas flow to the ripening system is performed under pressure of 3 bars, and its concentrations in chambers amount from 8 to 12 l/m$^3$. During one minute of gas ripening dosage inside ripening chamber around 0.714 l/min of gas is being spent for this type of chamber. For one working hour of decompression chamber (working fans, heaters, compressors, etc.), around 8.33 kWh is being spent, which is in average 200 kWh per day. For green fruit ripening in optimal time frame pf 120 h, around 1.000 kWh of electric power is being spent.

Preparation of green fruit for ripening is realized on the basis of standardized commercial procedures according to EHO-EU as plant constructor, as well as on the basis of procedures described in different studies [13 - 17]. Ripening technology as well as experiment realization, primarily consist of preparation of transport package (box) for ripening. On hermetically closed boxes in the hand hole area, a PVC wrapping is being cut in order for ripening gas to infiltrate.

Boxes prepared on the palette are then transferred from green chamber and manipulation area to ripening chambers. On the main computer ripening parameters are being adjusted: temperature, ripening gas concentration, ventilation, air flow blockage, etc. On the basis of determined starting temperature, from starting 13 °C fruit is being heated to required values. When fruit reaches required temperature, provided gas concentration is being added to the decompression chamber and chamber remains under air blockage for the next 24 h. After the expiration of the mentioned time, chambers are being ventilated with fresh air every 6 h in order to eliminate excess endogenous ethylene and $CO_2$, and also to provide the chambers with oxygen. With constant monitoring and regulation of ripening parameter, in normal processing conditions, between the fourth and the fifth day, fruit is in the phase 4 ripening scale. Then gradually fruit cooling begins, in every two hours one degree lower to optimal 13 °C, therefore ending the process.

Ripening degree indicator is practiced on the basis of standardized scale for fruit peel color sensor degree: 1) dark green hue; 2) light green hue; 3) more green than yellow hue; 4) more yellow than green hue; 5) yellow color with green tops; 6) completely yellow hue; 7) completely yellow hue with brown spots [18]. The research is performed in form of three factor experiment with following factors: 1) Fruit origin (country of origination) Ecuador, Columbia, Costa Rica; 2) Process temperatures (17 °C, 18 °C, 19 °C and 20 °C): 3) Ripening gas concentration (750 ppm, 900 ppm,1050 ppm and 1200 ppm) per chamber. During four years, on the sample of 144 successfully performed ripening treatments, where each modality was present with three repetitions, at the end of the process a fruit of satisfactory standardized quality was obtained with ripening degree of 4. A number of 72 factors significant for the ripening process were defined. Special significance for the very process and fruit process technology has the following group of 13 factors, as 13 variances:

1) OP01 - process temperature (°C), represents regulated temperature for banana ripening in range from 17 °C to 20 °C.
2) OP02 - concentration of ripening gas i.e. quantity of gas which initiates the ripening process, in the range from 750 ppm to 1200 ppm.
3) OP05 - month in which the banana reception and ripening process was performed.
4) UEC05 - fruit temperature at the entry (°C), i.e. recorded banana temperature value at the reception into the company, achieved during transport.
5) UEC06 - temperature deviations on reception, represents fruit temperature deviations (T opt.) from optimal 13 °C as standardized for fruit reception and derived from as follows:

$$Totp. = \frac{T\,pl.u.}{13-1} \quad (1)$$

6) PZ01 - green fruit ripening time in hours (h), i.e. real time for fruit ripening from Phase 1 to Phase 4.
7) PZ02 - percentage deviations from optimal 120 h for ripening, derived from:

$$Votp. = \frac{VD}{120-1} \quad (2)$$

where VD - is ripening time.

8) PZ03 - degree of standardized green fruit ripening expressed in percentage. Ripe banana fruit peel color in Phase 4 ripening degree.
9) PZ04 - degree of uneven fruit ripening (SND), calculated according to the following principle:

$$SND = 100 - SUD \quad (3)$$

where SUD - is the degree of standardized ripening.

10) PZ05 - ripening shrinkage (commercial loss during ripening process).
11) PZ06 - shrinkage participation in ripening (UKD) expressed in kg, calculated through:

$$UKD = \frac{KD}{GIK} \quad (4)$$

where KD - is ripening shrinkage; GIK - is guaranteed delivered quantity of fruit.

12) VC01 - green fruit storage time in ripening chamber in hours (h). The mentioned variance refers to green fruit storage time from delivery to ripening process.
13) MNPZ05 - green fruit storage time till delivery. Represents time that ripe fruit spends in storage chambers till delivery in market stores.

The data obtained on the basis of sample from 144 green fruit ripening treatments and 13 defined variances, are collected, statistically and analytically processed in the SPSS program. Verification of theoretic standard data allocation in the research is achieved by formal statistic "Shapiro-Wilk" test. Afterwards, a testing of noted differences was performed by formal statistic test with the help of ANOVA analysis as well as Krusal-Wollis H non-parametric test. By applying confirmatory factor analysis, a selection of factors (variances) significant for green fruit processing optimization was performed and their validity tested. By analyzing data, a set of factors was statistically processed which could have influence on optimal solution regarding obtaining the fruits of satisfying quality and at the same time for the company to achieve business efficiency.

Confirmatory Factor Analysis (CFA) or affirmatively factor analysis is one of the most represented methods used in researches [19]. It represents one of the

SEM methods (Structural equation modeling). The basis of this analysis is confirmation how many variances are fitting into the assumed structure. Confirmatory factor analysis is a measuring model which gives precision assessment for the measuring instruments. The analysis is used for examination of hypothetical models, in this case factors significant for optimization of green banana fruit processing.

## Results and discussion

Controlled method of green banana fruit ripening gives a possibility to provide the market and consumers every minute with high quality merchandise [12]. In order to obtain standardized quality during processing whilst healthy and safe for consumers and at the same time to achieve maximum business results with minimal investments, it is necessary to control every segment of the process in adequate manner. According to [20], management should be focused on efficient conducting of business processes, i.e. on all those factors functioning inside and outside the company.

In the purpose of ripening process optimization, it is necessary to know factors from external and internal environment which are significant to it, and most important is to manage and control these factors in the right manner, in order to achieve efficiency. Before the fruit ripening process, it is necessary to perceive characteristics and status of the fruit to determine on that basis a phase and optimal ripening treatment [21]. During research on this paper similar observations occurred, as well.

**Table 1.** Descriptive statistics of selected factors for process optimization.

| External and internal factors (variables) | The minimum | The maximum | Average | Standard deviations |
|---|---|---|---|---|
| OP01 | 17.00 | 20.00 | 18.50 | 1.12 |
| OP02 | 750.00 | 1200.00 | 975.00 | 169.22 |
| OP05 | 1.00 | 12.00 | 6.07 | 4.17 |
| UEC05 | 12.50 | 17.00 | 14.83 | 0.77 |
| UEC06 | -0.04 | 0.31 | 0.14 | 0.06 |
| PZ01 | 95.00 | 144.00 | 118.48 | 7.55 |
| PZ02 | -0.21 | 0.20 | -0.01 | 0.06 |
| PZ03 | 38.90 | 100.00 | 73.85 | 13.32 |
| PZ04 | 5.60 | 61.10 | 26.88 | 12.57 |
| PZ05 | 146.00 | 399.00 | 275.07 | 52.97 |
| PZ06 | 0.01 | 0.02 | 0.01 | 0.00 |
| VC01 | 1.00 | 336.00 | 72.44 | 74.29 |
| MNPZ05 | 1.00 | 96.00 | 17.49 | 20.24 |

Basic factors of ripening process and parameters which affect fruit processing are temperature and ethylene concentration in the ripening chamber. From Table 1 it can be seen that average process temperature was 18.5 °C. Temperatures which were set during ripening on the sample from 144 treatments were in the range of 17 °C to 20 °C. The selected process temperatures are in accordance with the standardized temperatures described and used by other authors in their research [22, 23]. For regulated green fruit ripening, commercial banana sorts require temperature in the range from 14.4 °C to 18 °C, while in certain cases fruits require temperature of 20 °C.

As already mentioned, artificial means are being used for initiating and improving ripening process. For initiating the ripening process, in this area and this research, ripening gas (ethylene) was used in average concentration of around 975 ppm. The lowest recorded gas concentration used in this research was 750 ppm, while maximum achieved gas concentration was 1.200 ppm. The mentioned values are in accordance with concentrations also used in other research [24]. Saltveit [24] states that for commercial purposes of fruit ripening, ethylene concentrations are used from 10 to 1000 $\mu L\ L^{-1}$, on the basis of aforementioned quantities provide standardized fruit peel color. Lower values cause the appearance of uneven ripening, and consequences could be bad chamber pressurization and gas leakage from chambers [24].

The best month for fruit ripening during this research was recorded in June. The average temperature of the green fruit on the reception was 14.83 °C, while maximum was 17 °C, which is a bad indicator for further processing, therefore reflecting on the quality in all segments of the production. Much better indicator was recorded value of 12.5 °C, which was close to standardized green fruit temperatures on the entry, which during the further process gave significantly higher quality with minimal losses. Cooling process of fresh fruits and vegetables in cold storage, represents basic method of product quality preservation. However, storing fruits in cold conditions (low temperatures), can cause damages and frostbites known as „cold injuries“. If banana fruits are stored in temperatures below 13 °C (and significantly lower under 12 °C) before or after harvest, in transport and during manipulation in storage (for storing, ripening and sale), it comes to fruit colds, occurrence of black spots and flecks on the green peel surface as well as inside of the fruit, fruit peel darkening causing later degradation and softening, i.e. occurrence of so called „burns“ [25]. Therefore, prevention of every deviation from standard procedures, affect optimization and efficiency of the process. The average temperature deviations on reception were around 0.14% and in the range from -0.04% to 0.31%.

The time that was necessary for the fruit to reach Phase 4 degree after ripening process is 118.4 h. Certain fruits required less time in average 95 h, while others required significantly longer time to ripe in average 144 h. Depending on the starting temperature, ripening cycles can last 4 days at temperatures around 18 °C and higher or significantly longer from 8 to 10 days at temperatures which are lower and around 14 °C [32].

Also, in other research it came to the fact that temperature has importance regarding ripening process [26], where it was concluded that banana fruits, in order to achieve consumable ripeness, needed in average 104.7 h. In case of Chiquita brand, banana required the most time (108.1 h), and of Consul brand the least time (102.4 h) to reach consumable ripeness. Temperature has shown a significant influence on fruit ripening time. At the temperature of 20 °C fruits reached consumable ripeness for 98.9 h, while at the temperature of 18 °C it required around ten hours more to reach ripeness [26].

On the basis of the observed, it can be concluded that temperature and ethylene concentration have significant influence on ripening process time and by their regulation production process optimization can be affected. It can also be noted from factors „deviation from optimal ripening time (planned-standardized 120 h) where during research variation was around -0.14%, in range from -0.21% to 0.20%. According to the obtained values, on the sample from 144 treatments certain mode of efficiency was achieved regarding process duration time shortening, which takes with it a decrease of power demand, decrease in working labor, decrease in losses, etc.

Commercial loss of the process, (ripening shrinkage) realized during ripening, is in the average of around 275 kg. In relation to received guaranteed quantity (19.536 kg) loss is around 1.4%. Regarding losses incurred in the banana processing realized in other parts of the world [27], the values obtained in this paper look pretty optimistic. Banana losses in developing countries are from 20 to 40%. Lesser fruit losses are in developed countries (from 10% to 15%) as a consequence of harvest and season [12]. Research showed that in less developed countries losses are up to 80% [27, 28].

During this research, there were treatments with losses in shrinkage of around 400 kg, at maximum. However, some of the treatments have losses of only 144 kg. On the basis of the previously stated, it can be noted that by temperature correction, ethylene concentration and other factors influencing ripening shrinkage (loss) can be affected upon during process. One of the factors of weight loss during process is fruit dehydration during fruit respiration caused by the influence of high ripening process temperatures. According to [29], water circulation inside banana fruit during the process, affects fruit peel firmness. Increase of transportation manifested in this manner affects water loss and therefore fruit weight [29].

During research, fruit of Cavendish brand from Ecuador, Costa Rica and Colombia, had unified peel color and quality after ripening in the average of 73.8%. Variations regarding unification were in the range from 38.9%, which is not a good indicator. It points out that by regulating the factors, banana peel color unification can be influenced upon. Commercial technology of fruit ripening, besides biochemical alterations inside and on the fruit (not visible nor sensible and performed in laboratory conditions), as a counterpart of fruit ripening grade, denoted detection of peel color sensor alterations starting from very green to yellow. The same methods were also used in this experiment as well as in other research, in which it is stated that color alteration starts and varies from the middle of the banana fruit, then further on to the top ends, whereat inadequate regulation of process parameters can cause unstandardized peel color [30]. Regarding unstandardized fruit color during this research, banana had bad color in the average of around 26%. The biggest value of bad fruit color is 61%, as a bad indicator, while the best color in average was 5.6%, which is a very good value and banana quality.

In case of variance „storage time for green and ripe bananas“, optimization fall is a consequence of cost increase caused by prolongation of merchandise storing time, power demand, working labor costs, maintenance costs and depreciation, etc. Besides the mentioned, lengthened storage in the ripening chamber worsens the freshness of the merchandise, which by itself with reduced quality creates additional unnecessary costs. Green fruit storage time in average was 72 h, and ripe was around 18 h. Values can be significantly higher as shown by the obtained data. Minimum storing time of green and ripe fruit in storage recorded was of just 1 h. The mentioned time was spent on reception and distribution, respectively merchandise handling during green fruit storing and distribution of ripe fruit after ripening.

On the other hand, bad sales projection plan, bad stock control, bad process organization, poor fruit quality, poor working labor organization, etc. affected time increase for fruit storing. With green fruit, values are recorded of even 336 h and with ripe of 96 h, company storing, which are not good indicators.

In order to examine validity of the selected data i.e. parameters of banana processing in Logistic Distribution Centre Niš, on 13 selected variances (factors) which have influence on optimal solutions and green fruit processing technology, a verification of theory normality in research data allocation was firstly performed.

Allocation normality verification was practiced by "Shapiro-Wilk" test, where test statistics and degree of freedom represent data by which limit value of error probability can be found. Error probability shows whether the test value is statistically significant or not. Variables which are smaller on the test from limit values (0.005) differ from theoretic allocation.

On the basis of data from Table 2 all values which are smaller than P=0.05 are significant for this research. This means that their allocations didn't happen by accident but there is a certain factor causing and altering appearance in reality i.e. there is a causal connection. From 13 variables, 5 were obtained that differ and are statistically significant: OP01 - process temperature C; OP02 - ripening gas concentration; OP05 - ripening month; VC01 - green fruit storage storing time; MNPZ05 - ripe fruit storing time inside ripening chamber.

**Table 2.** Verification of theory normality in data allocation for process optimization research

| External and internal factors (variables) | Test statistics | Degree of freedom | Standard deviations |
|---|---|---|---|
| OP01 | 0.856 | 144 | 0.000 |
| OP02 | 0.854 | 144 | 0.000 |
| OP05 | 0.849 | 144 | 0.000 |
| UEC05 | 0.988 | 144 | 0.232 |
| UEC06 | 0.988 | 144 | 0.231 |
| PZ01 | 0.979 | 144 | 0.066 |
| PZ02 | 0.979 | 144 | 0.069 |
| PZ03 | 0.969 | 144 | 0.050 |
| PZ04 | 0.969 | 144 | 0.039 |
| PZ05 | 0.988 | 144 | 0.231 |
| PZ06 | 0.987 | 144 | 0.218 |
| VC01 | 0.841 | 144 | 0.000 |
| MNPZ05 | 0.754 | 144 | 0.000 |

"Shapiro-Wilk" test

In further work, the obtained data were tested by formal statistical test in order to detect differences. Table 3 reports the detected differences.

In purpose of obtaining higher security and precision, all variables of process optimization were treated with source of genesis (country of origin: Ecuador, Costa Rica, Colombia). ANOVA parameter test was performed for variables fulfilling the condition as follows: UEC05 - fruit temperature on reception; UEC06 - temperature deviations on reception; PZ01 - ripening time per hours; PZ02 - percentage deviations from 120 h of ripening; PZ03 - degree of green fruit unified ripening; PZ04 - degree of unstandardized ripening; PZ05 - ripening shrinkage; PZ06 - participation of shrinkage in fruit ripening.

**Table 3.** Testing of detected differences by formal statistic test in process optimization research

| External and internal factors (variables) | Country | | | ANOVA | |
|---|---|---|---|---|---|
| | Ecuador | Costa Rica | Colombia | "F" test | Standard deviations |
| OP01 | 18.50 | 18.50 | 18.50 | *KCT | 1.000 |
| OP02 | 975.00 | 978.13 | 971.88 | *KCT | 0.984 |
| OP05 | 4.52 | 6.56 | 7.13 | *KCT | 0.005 |
| UEC05 | 14.60 | 14.86 | 15.04 | 4.276 | 0.016 |
| UEC06 | 0.1229 | 0.1428 | 0.1572 | 4.274 | 0.016 |
| PZ01 | 119.71 | 118.75 | 116.98 | 1.629 | 0.200 |
| PZ02 | 0.00 | -0.01 | -0.03 | 1.630 | 0.200 |
| PZ03 | 67.37 | 71.88 | 82.29 | 20.054 | 0.000 |
| PZ04 | 32.63 | 28.12 | 19.89 | 15.217 | 0.000 |
| PZ05 | 285.69 | 272.83 | 266.69 | 1.622 | 0.201 |
| PZ06 | 0.0146 | 0.0140 | 0.0137 | 1.615 | 0.203 |
| VC01 | 56.33 | 76.23 | 84.77 | *KCT | 0.157 |
| MNPZ05 | 16.42 | 15.10 | 20.94 | *KCT | 0.336 |

*Krusal-Wollis H test

Formal statistic test was performed in the purpose of obtaining a group of tests (comparing parameter and non parameter tests) for further analysis. For mentioned 5 variables which did not fulfill the condition, a non parameter Krusal-Wollis H test was performed equivalent to (counterpart) ANOVA.

The results obtained in the Table 4 represent comparison of connection strength through correlation coefficients between variables and research data performed in banana ripening chamber.

**Table 4.** Correlation matrix between process optimization variables

| variables | OP01 | OP02 | OP05 | UEC05 | UEC06 | PZ01 | PZ02 | PZ03 | PZ04 | PZ05 | PZ06 | VC01 | MNPZ05 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| OP01 | 1.000 | 0.006 | -0.238 | -0.304 | -0.304 | -0.532 | -0.532 | 0.639 | -0.651 | -0.049 | -0.050 | -0.274 | -0.310 |
| OP02 | 0.006 | 1.000 | 0.061 | -0.113 | -0.113 | -0.155 | -0.155 | 0.256 | -0.245 | -0.083 | -0.082 | -0.028 | 0.030 |
| OP05 | -0.238 | 0.061 | 1.000 | 0.087 | 0.087 | -0.037 | -0.037 | -0.093 | 0.087 | 0.103 | 0.104 | 0.048 | 0.091 |
| UEC05 | -0.304 | -0.113 | 0.087 | 1.000 | 1.000 | 0.042 | 0.042 | -0.113 | 0.134 | -0.046 | -0.045 | -0.011 | 0.099 |
| UEC06 | -0.304 | -0.113 | 0.087 | 1.000 | 1.000 | 0.042 | 0.042 | -0.113 | 0.134 | -0.046 | -0.045 | -0.011 | 0.099 |
| PZ01 | -0.532 | -0.155 | -0.037 | 0.042 | 0.042 | 1.000 | 1.000 | -0.516 | 0.495 | 0.032 | 0.033 | 0.088 | 0.264 |
| PZ02 | -0.532 | -0.155 | -0.037 | 0.042 | 0.042 | 1.000 | 1.000 | -0.516 | 0.495 | 0.032 | 0.033 | 0.088 | 0.264 |
| PZ03 | 0.639 | 0.256 | -0.093 | -0.113 | -0.113 | -0.516 | -0.516 | 1.000 | -0.946 | -0.049 | -0.049 | -0.048 | -0.122 |
| PZ04 | -0.651 | -0.245 | 0.087 | 0.134 | 0.134 | 0.495 | 0.495 | -0.946 | 1.000 | -0.028 | -0.027 | 0.041 | 0.149 |
| PZ05 | -0.049 | -0.083 | 0.103 | -0.046 | -0.046 | 0.032 | 0.032 | -0.049 | -0.028 | 1.000 | 1.000 | 0.303 | 0.121 |
| PZ06 | -0.050 | -0.082 | 0.104 | -0.045 | -0.045 | 0.033 | 0.033 | -0.049 | -0.027 | 1.000 | 1.000 | 0.304 | 0.122 |
| VC01 | -0.274 | -0.028 | 0.048 | -0.011 | -0.011 | 0.088 | 0.088 | -0.048 | 0.041 | 0.303 | 0.304 | 1.000 | 0.107 |
| MNPZ05 | -0.310 | 0.030 | 0.091 | 0.099 | 0.099 | 0.264 | 0.264 | -0.122 | 0.149 | 0.121 | 0.122 | 0.107 | 1.000 |

Correlation coefficient interval is in the limits from -1 to +1. The level of the coefficient of correlation between variables for this analysis is over ± 0.3. On the basis of the obtained data from Table 4. correlation coefficients are mainly smaller than 0.3 which gives a possibility for continuation of analysis. They are relevant and represent a good selection of further work, because there is no high multicollinearity among indicators. Representing exemption is a variable with code name „OP01“, respectively ripening process temperature. This variable in several cases correlates with higher coefficient from other variables, but is of no great importance for further research.

The next step represents verification of model justifiability, in order for the mentioned model to be used for further research. Table 5 presents main factors analysis preliminary tests.

**Table 5.** Preliminary tests for analysis of main factors

| | | |
|---|---|---|
| Kaiser-Meyer-Olkin Measure of Sampling Adequacy. | | 0.611 |
| Bartlett's Test of Sphericity | Approx. Chi-Square | 6016.074 |
| | Df | 78 |
| | Standard deviations | 0.000 |

From Table 5 in the first test (Kaiser-Meyer-Olkin Measure of Sampling Adequacy), it is detected that the obtained value is higher than 0.6. In other confirmatory test (Bartlett's Test of Sphericity) it can be seen that the error is smaller than 0.01. On the basis of the mentioned values, statistical significance can be concluded. The results obtained by analysis tests of main components, justify the selection of variables affecting the banana fruit process optimization, where measuring scale in sense of methodology suits the appearance in research.

On the basis of Extraction variance, a calculation of joint fluctuations was performed, where maximum value tends to one. In other words, variables with higher value also have a joint variance with larger group of variables from research experiment. From Table 6, it can be seen that most of the variables have joint variance, which is in certain cases very close to theoretic communality from one whole variables, so called saturation.

**Table 6.** Communality explained by variance in variable

| External and internal factors (variables) | initials | Variance extracted |
|---|---|---|
| OP01 | 1.000 | 0.769 |
| OP02 | 1.000 | 0.627 |
| OP05 | 1.000 | 0.273 |
| UEC05 | 1.000 | 0.967 |
| UEC06 | 1.000 | 0.967 |
| PZ01 | 1.000 | 0.752 |
| PZ02 | 1.000 | 0.752 |
| PZ03 | 1.000 | 0.762 |
| PZ04 | 1.000 | 0.752 |
| PZ05 | 1.000 | 0.950 |
| PZ06 | 1.000 | 0.949 |
| VC01 | 1.000 | 0.307 |
| MNPZ05 | 1.000 | 0.392 |

Table 7 presents the total explained variability of principal component analysis.

**Table 7.** Total explained variability of principal component analysis

| Components | Basis equivalents of variance | | | Extracted summed component variabilities | | |
|---|---|---|---|---|---|---|
| | total | % of variance | Cumulative % | Total | % of variance | Cumulative % |
| 1 | 3.825 | 29.426 | 29.426 | 3.825 | 29.426 | 29.426 |
| 2 | 2.229 | 17.145 | 46.571 | 2.229 | 17.145 | 46.571 |
| 3 | 1.963 | 15.103 | 61.674 | 1.963 | 15.103 | 61.674 |
| 4 | 1.201 | 9.237 | 70.911 | 1.201 | 9.237 | 70.911 |
| 5 | 0.992 | 7.573 | 79.484 | | | |
| 6 | 0.869 | 6.687 | 86.170 | | | |
| 7 | 0.771 | 5.934 | 92.104 | | | |
| 8 | 0.731 | 5.624 | 97.729 | | | |
| 9 | 0.246 | 1.893 | 99.621 | | | |
| 10 | 0.049 | 0.378 | 100.000 | | | |

"Extraction Method: Princ al Co onent Ana sis".

By applying" Equamax" („Rotation Method: Equamax with Kaiser Normalization."), standing out are variables which correlate the most and form a group of similar factors that have impact on some occurrence. Kaiser value with grade higher than one separates and calculates joint variability in relation to formed factor. The chart of process optimization factors is shown in Figure 1.

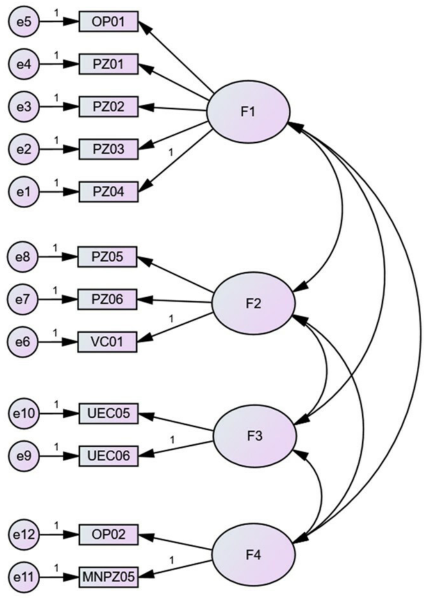


**Figure 1.** Chart of process optimization factors

From Figure 1 on the chart of process optimization factors, four groups of variables are detected which will give a new character to the research of the analyzed occurrence in subject:

- F1 group consists of 5 variables: OP01 - process temperature; PZ01 - ripening time; PZ02 -percentage deviation from planned ripening time (120 h); PZ03 - degree of unified green fruit ripening; PZ04 - unified ripening degree.
- F2 group consists of 3 variables: VC01 - green fruit storing time in ripening chamber; PZ05 - ripening shrinkage;

PZ06 - participation of shrinkage (commercial loss) during ripening.

- F3 group consists of 2 variables: UEC05 - fruit temperature on reception; UEC06 - temperature deviations on reception.
- F4 group consists of 2 variables: OP02 - ripening gas concentration; MNPZ05 - green fruit storing time until delivery.

Figure 2 shows scatter diagram of process optimization.

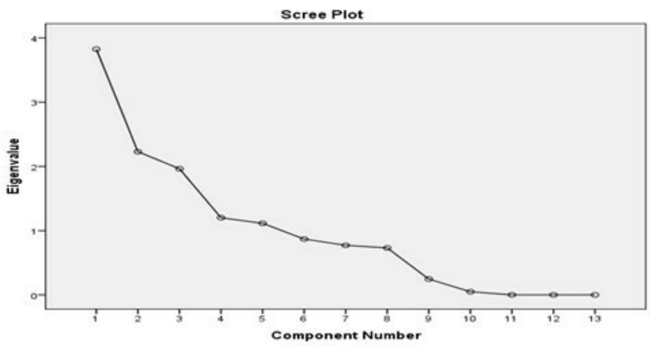


**Figure 2.** Scatter diagram of process optimization

Figure 2 shows that the landmark line is after fourth component. Kept in the analysis are 4 groups of factors explaining 71% of variabilities for this analysis. Matrix of rotation factors is shown in Table 8.

**Table 8.** Matrix of rotation factors with its saturations on the basis of each first component indicators

| | Factors | | | |
|---|---|---|---|---|
| External and internal factors (variables) | 1 | 2 | 3 | 4 |
| OP01 | -0.709 | -0.092 | -0.321 | -0.369 |
| OP02 | -0.286 | -0.174 | -0.180 | 0.658 |
| OP05 | 0.016 | 0.158 | 0.184 | 0.370 |
| UEC05 | 0.033 | -0.041 | 0.981 | 0.051 |
| UEC06 | 0.033 | -0.041 | 0.981 | 0.051 |
| PZ01 | 0.851 | 0.000 | -0.068 | 0.189 |
| PZ02 | 0.851 | 0.000 | -0.068 | 0.189 |
| PZ03 | -0.869 | -0.074 | -0.141 | 0.176 |
| PZ04 | 0.869 | 0.074 | 0.141 | -0.176 |
| PZ05 | -0.012 | 0.973 | -0.027 | -0.003 |
| PZ06 | -0.012 | 0.973 | -0.026 | -0.001 |
| VC01 | 0.091 | 0.474 | -0.005 | 0.284 |
| MNPZ05 | 0.250 | 0.140 | 0.081 | 0.591 |

„Rotation Method: Equamax with Kaiser Normalization."

First group of factors (F1), named „ripening internal factors", explains 29.4% of green banana fruit optimization process, on the basis of performed confirmatory factor analysis. These variables represent most important factors in the research and have the highest significance on banana ripening thermal process. From Table 8 it concludes that all those values closer to one, have higher significance for the process. The more coefficient correlates with factor, the higher variable value is.

From the mentioned first group, the highest positive value has a degree of unstandardized ripening (0.869). Increase of fruit quantity with unstandardized peel color, adversely reflects on process optimality. On the other hand, with decreasing unstandardized fruit peel color degree during ripening, a percentage of fruit increases which regarding uniformity has a higher percent (0.869), respectively more expressed hue and peel color, thus affecting process optimization. Introduced data are of statistical significance and by their regulation process efficiency is achieved. To similar results that unification degree can be influenced also came other authors who state that fruit peel color alteration is a consequence of chlorophyll degradation during ripening occurring due to increase of temperature during production [31]. In situations when it comes to increase of fruit temperature chlorophyll slightly drops where fruit in time loses green color, and gradually gains yellow [31]. According to [32,33] energy is considered as a key resource, while its consumption should be monitored and controlled. In research by Ahmad and assist. [34] it came to the following observations: banana fruits that ripened firstly at 18 °C, so in time temperature altered to 20 °C, had drastically less green color on their peel, in time during ripening process better fruit unification was achieved; fruits that firstly ripened at 16 °C, than altered to 20 °C, had less peel color unification from the first group where initial temperature was 18 °C. Fruits which were in early ripening stages, had significantly more green color on them than yellow, in relation to fruits which were in the later ripening stages, where yellow was more expressed than green color [34].

Variable, ripening time, has high value of correlation coefficient (0.851). Longer time for fruit ripening provides more optimal solution towards obtaining better banana quality with higher peel color unification, higher sugar fruit quantity, better flavor, etc. But, on the other hand, it can increase asset costs and available resources (electric power, working hours for employees, increase of total costs etc.), but also to shorten best before date of the fruit in sales. According to [34], on time length of the processing i.e. time for fruit ripening, set process temperature has great influence. Bananas that ripen at lower temperatures (14, 16 and 18 °C) require significantly longer time to get unified color suitable for sale. Fruits that ripen at higher temperatures of around 20 °C, get more unified fruit peel color for shorter time period [34].

Identical assertions can also be introduced for variable percentage deflection from planned ripening time whose correlation coefficient is also high (0.851). According to [26], average time required for the banana fruits to reach consumable ripeness was 104.7 h, Chiquita brand required the most (108.1 h), and Consul fruits brand required the least ripening time (102.4 h). Every time shortage from optimal 120 h of fruit ripening can, on one hand have negative effects regarding quality degradation (crudeness, color unevenness, poor flavor, low sugar level, etc.), and on the other hand be positive regarding decrease of losses (lesser consumption of energy resources, lesser working hours for employees, etc.). With increase of processing time deflecting from 120 h, positive values are on the fruit quality side, but negative are raising costs of raw materials and production.

That decrease of production costs as well as costs per product unit in the company is of great importance for business was also stated by other authors [35 - 37]. Management and rational use of power resources, besides the significance for efficiency and cost-effectiveness on micro level, it is also significant for macro economy and has a much wider sense. Good realization and strategy for energy and energy resources management is of great importance for social-economic sustainability of one country, social prosperity, preserving natural resources and therefore the environment [38].

Variable "process temperature" has negative correlation whose coefficient is rather high (-0,709). Decrease of temperature affects process optimality regarding correction of use for certain resources in production (consumption of electric power for heating). On the other hand, lower temperatures, in negative sense, affect increase of process time length, increase in workers quota, worsening quality, etc. In [26] values are obtained which show that temperature significantly affected ripening time as follows: at temperature of 20 °C fruits reached consumable ripeness in 98.9 hours, while at the lower temperature (18 °C) it required around ten hours more (110.5 h) for fruit ripening.

Variable „process temperature" in most cases is in correlation with ripening gas concentration. With increase of fruit ripening temperature from 18 °C to 21 °C, it comes to process time shortening for 27 h and consumption fall of ethylene concentration for 360 ppm per one ripening inside decompression chamber. In mentioned case gas savings were made of 8.568 L/min., saving expressed in value of 765,80 RSD without VAT (8,568 L/min. x 89,38 RSD price of ethylene per liter) [39].

Second group of factors (F2) is of statistical significance for research. This group is called "ripening process side factors" and explains 17.1% of process optimization. Variables in this group are post-process factors affecting the production after thermal fruit processing. Correlation coefficient for variable process shrinkage is extremely high, close to one (0.973). From the obtained data it can be concluded that the higher the value of the loss is, the higher the probability is not to obtain optimal solution during the process regarding fruit processing. According to [40], fruit softening and weight loss during the process is a consequence of: first - starch reduction in soluble carbon hydrates; second - degradation of pectin substances; and third - water circulation from pulpy part towards fruit peel during ripening. High temperature causes rapid fruit breathing. Then it comes to banana dehydration, whereupon fruit loses water from its composition, causing decrease in weight, therefore emergence of higher commercial loss.

Identical situation is in the case of variable "participation of commercial loss during ripening" which also records high correlation coefficient (0.973). Data of other authors state that losses can be affected on [27, 28]. It can be concluded that by controlling fruit quality at reception and during processing, by controlling supplies, by adequate process management, by controlling parameters directly or indirectly affect processing, influence can be made on decreasing of total losses and therefore process optimization.

Third group of factors (F3) explains 15.1% of variances and is called „external factors". Variables relate to factors of external environment indirectly affecting processing and on those which in most cases employees in the ripening chamber have no influence but are of statistical significance for final outcome of banana processing. A representative of this group fruit temperature at reception stands out whose correlation coefficient is extremely high (0.981). High temperature at entry is in direct connection with the quality of the received fruit. The more fruit temperatures at reception are higher, fruit quality is seriously under question mark, and in total it additionally reflects on the process and final outcome in banana quality. Increase of bad quality disproportionately affects process optimization. Observed from another angle, higher fruit temperature at entry can provide certain form of cost-effectiveness because less electric power, working labor, etc. is used for heating. But this is not a good solution and long-term option, due to possible losses in further process, which are a consequence of bad merchandise reception at storage entry. Also, variable „temperature deflection "points to how much banana temperature deflected from optimal 13 °C as unified temperature for green fruit reception. The more the percentage is higher, the more the plausibility of bad fruit quality appearance in production is.

The fourth group of factors (F4) of statistical significance for research explains 9.2% of variances and is called „other group of factors". This group is made of variables representing ripening factors which directly or indirectly affect fruit ripening, therefore important for process optimization. Variable OP02 - *ripening gas concentration* falls out from the first group of factors F1 to which by its nature belongs more. Correlation coefficient of this variable is 0.658. According to [8], at higher gas concentration use of 120 ppm, it comes to process time shortening to 91 h (for 29 h less in relation to optimal 120 h), which is not negligible. On the other hand, low gas concentration of 600 ppm, prolonged ripening process time to 131 h, (for 11 h more in relation to optimal 120 h). In both cases at temperature concentration of 18 °C it did not come to the worsening of quality, fruit reached Phase 4 on the ripening scale [8].

Other factor represents *fruit storage time in ripening chamber*, where coefficient of this variable is 0.591. With decreasing of time which fruit spends during storing in ripening chamber asset costs are decreasing, and therefore affecting the process optimization. Longer storing time affects fruit quality worsening in storage and ripening chambers.

According to [41], during this research it came to similar observations, in the world market there are defined criteria affecting the price of green and ripe banana as follows: fruit quality after harvest, preserved freshness, maintained quality during transport and storage. Good delivery, preserved structure and fruit quality can cost more than double from bad quality bananas [41]. On that basis it can be stated that by optimization of supplies, outlet plan good projection, adequate fruit distribution and sales, etc., time spending for bananas inside storing and ripening chambers can be affected.

According to [39], the best fruit ripening results on the territory of Republic of Serbia were achieved at ripening gas (ethylene) concentration of 900 ppm, on fruit exposure at temperature from 18 °C during the treatment of 120 h. With these parameters regarding ripening gas consumption processing costs were decreased by 7.14 l/min (for 50.1%) in relation to treatment where gas dosage concentration was 1.200 ppm. Respectively, saving of ripening gas was achieved of 100 ppm in relation to commercial 1.000 ppm spoken by Thompson and Seymour in their works [40]. By parameter corrections respectively ripening factors and their interaction (correlating) it was also stated in this research that cost decrease can be affected as well as achieving higher efficiency in ripening process.

On the basis of performed confirmatory factor analysis, selection of factors in this research is in 71% cases relevant for obtaining parameters providing optimal solutions regarding banana green fruit processing in ripening chambers in this region. It is confirmed that certain variable groups have joint variability and that variables function together. On the basis of everything stated as well as obtained data from aforementioned analysis, it can be confirmed that by adequate application of banana ripening factors an optimization of green fruit technological processing is achieved.

## Conclusion

Every technology in production, including thermal processing of green banana fruit, requires constant upgrading and new solutions in order to provide higher efficiency and system functionality. In the purpose of process optimization and upgrading technology for banana ripening, the factors with the most importance on fruit processing optimization were defined. On the sample from 144 ripening treatments realized on the territory of Republic of Serbia, in the chambers of Logistic Distribution Centre Niš, the parameters of importance for the processes and product end quality were examined. Out of the group of 72 internal and external factors, 13 indicators were selected i.e. variables with the highest impact on process optimization were defined.

On the basis of more test application (“Shapiro-Wilk", Krusal-Wollis H non-parametric test, ANOVA analysis) as well as the use of key confirmatory factor analysis, a group of 4 factors was obtained.

A lot of factors of external nature affect technology of banana ripening directly or indirectly, and for the ripening process far more significant are internal factors including: temperature, ripening time, ethylene concentration, human factor, etc.

Exactly the first group (F1) is made by internal factors of ripening process and it explains 29.4% of variance. This group is made by the following variables with high correlation coefficient: process temperature (-0.709), ripening time (0.851), deflection from planned ripening time (0.851), degree of unified ripening (-0,869), degree of uneven ripening (0.869). According to its nature and importance for production, as well as on the basis of this research and other authors mentioned in this paper, from this group a ripening gas concentration variable fall out a joined second group, but its importance was not neglected in theoretic and practical respect.

The second group (F2), according to importance consists of by-/post- factors incurred after processing, which explains 17.1% of variance. With high correlation coefficient, the following variables were present in the F2 group: ripening shrinkage (0.973), participation of ripening commercial loss (0.973).

The third group (F3) are external ripening factors with variance explanation of 15.1%. The following variables are presented here: fruit temperature on entry (0.981) and temperature deflection at reception (0.981).

In the end, the fourth group F4, consisting of other factors with variance explanation of 9.2%. The next variables from this group have the lowest correlation coefficient: ripening gas concentration (0.658), fruit storing time in chamber (0.591).

On the basis of the performed analysis and obtained data, the factors were selected, which were in 71% of cases relevant for green fruit processing optimization. It has been proven that the regulation of certain external and internal factors can directly or indirectly influence the green banana ripening process, in order to obtain a standardized fruit quality. It is important for the company because the regulation of the mentioned factors contributes to better efficiency and reduction of costs and losses.

This paper provides a possibility for further research on set factor model, as well as verified solutions applicable in practice, yet important for efficient company business in which green banana fruit processing is being realized.

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**Izvod**

# DEFINISANJE ČINILACA ZNAČAJNIH ZA OPTIMIZACIJU I UPRAVLJANJE TEHNOLOŠKIM PROCESOM DOZREVANJA ZELENOG PLODA BANANA

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Rad ima za cillj definisanje činilaca koji utiču na optimizaciju procesa i unapređenje tehnologije dozrevanja zelenog ploda banana, ne samo na teritoriji Republike Srbije gde je sprovedeno istraživanje, već i šire. Na uzorku od 144 tretmana zrenja ploda, u vidu trofaktorijalnog ogleda sa tri glavna parametra (zemlja porekla, temperature procesa i koncentracija zreonog plina) ispitivan je uticaj činioca od značaja za proces proizvodnje i krajnji kvalitet ploda. Iz grupe od 72 interna i eksterna pokazatelja, odabrano je i formirano 13 varijabli sa najvećim uticajem na efikasnost i optimalnost procesa. Primenom više testova (“Shapiro-Wilk&quot, Krusal-Wollis H neparametrijskog testa, ANOVA analize) kao i na osnovu ključne konfirmatorne faktorske analize, dobijena je grupa od 4 faktora. Prvu grupu F1 čine interni činioci procesa dozrevanja i ona objašnjava 29.4% varijanse, i u toj meri značajna je za optimizaciju procesa. Drugu grupu F2 čine nus ili postčinioci nastali nakon procesa dorade, koji objašnjavaju 17.1% varijanse. Treća grupa F3 su eksterni činioci dozrevanja sa objašnjenjem varijanse od 15.1%. Na kraju, četvrta grupa F4, gde se nalaze ostali činioci značajni za doradu i optimizaciju procesa dozrevanja, sa varijansom od 9.2%. Istraživanje je pokazalo da se u 71% slučajeva adekvatnim uparivanjem i regulacijom odabranih činilaca može uticati na optimizaciju procesa dorade banana i njegovu efikasnost, a da se pritom dobije zadovoljavajući kvalitet ploda i ostvari dobit. Rad ostavlja mogućnost za dalja teorijska istraživanja i od velikog je značaja za preduzeća u kojima se odvijaju procesi dorade ploda banana u kontrolisanim uslovima.

**Ključne reči:** banana, tehnologija dozrevanja, optimizacija procesa, efikasnost, konfirmatorna faktorska analiza